

Dental Caries in the Second Millennium

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Summary

The Consensus Development Conference on Dental Caries Diagnosis and Management Throughout Life was organized to answer specific questions related to the diagnosis of early and advanced carious lesions; indicators of caries risk; methods for primary prevention of dental caries; methods for arresting early carious lesions; and clinical decision making. For some of these issues, as the subsequent reviews will show, we have made significant progress in finding answers; but, unfortunately for others, the evidence is either weak or not yet available.

This narrative historical review of dental caries diagnosis and management throughout the millennium is based on information obtained from reports published between 1839 and 1965 and 40 textbooks on caries diagnosis and management published since the 19th century. A hand search of the Index of Dental Literature published between 1839 and 1965 located relevant publications on caries diagnosis, etiology, prevention, and management. Additionally, we have selected a number of articles published after 1965 because of their relevance to the topics reviewed in this paper.

The history of understanding of any disease or condition in humans has passed through two distinct eras. The first, which lasted until the 20th century, and may still be ongoing today, is the “observational” era. The second, which has developed and revolutionized our understanding of the causes and treatments of all diseases, is the “scientific” era. During the observational era, healers treated their patients using reason, logic, and their contemporary knowledge. They provided treatments without evaluating their outcomes. During the scientific era, we contend that we are still in the gray years of the “restorative era” and in the midst of the “preventive era” where the emphasis would soon shift towards early detection of biological markers of diseases and prevention of their initiation and progression.

Many of the issues to be discussed at this conference have been observed since the 19th century. For example, dentists reported on the presence of enamel and dentinal caries (early and advanced lesions) as early as the 1880s.(1) Hidden caries (defined as “caries in the dentin without an opening through the enamel leading to it.”) was noticed in 1868. (2) “Secondary decay” was discussed as a problem in 1880.(3) Early childhood caries, or “labial decay of childhood” was described in 1884. (1) Interestingly, the problem of variation among dentists in caries diagnosis and restorative treatment decisions was reported on in 1869.(4) The cause of this ongoing problem was proclaimed to be the “failure in diagnosis of dental decay, even when one intends to be very thorough”. The cause of variation was attributed to “the large size of the excavator used for examination”, and the solution proposed was to use “the very smallest...hatchet ...with exceedingly thin blade”.(4) During the observational era, there were several competing theories of the etiology of dental caries. One theory that gained wide support during the 20th century is the chemico-parasitic theory. (5)

The scientific era in dentistry started in the early years of the 20th century with attempts to test hypotheses and collect data to support or refute them. Basic research led to significant advances in the understanding of the histopathology of caries in enamel and dentin, microbial risk factors, physiology and pathology of saliva, and understanding of the mechanisms of actions of fluorides. Research activities led to the development of new preventive interventions (for example, sealants) and restorative materials that have had significant impact on the restoration of decayed teeth and the retention of teeth for life.

In the US, oral health emerged as a focus for initiatives sponsored by government agencies during and after World War II as a result of the relatively large number of potential recruits who did not meet the dental requirements for military service. At the same time, the link between fluoride, fluorosis, and dental caries was confirmed by a number of cross-sectional and longitudinal studies (6-8). This link was the first major breakthrough in caries prevention. In 1945, the first field trial to test the effectiveness of water fluoridation commenced in the US. (7) The water fluoridation studies led to the wide spread use of fluoride in caries prevention.

The etiological model proposed by Miller was expanded to include other risk factors or indicators that are associated with dental caries initiation and progression. Dental caries is now considered to have a multifactorial etiology.(9) Dental caries is also recognized as a biosocial disease. The burden of disease has shifted from the affluent members of society to those who are economically disadvantaged.

During the scientific era of the 20th century, the prevalence and severity of dental caries in the US have declined, especially in children. There has been a phenomenal growth in the biological understanding of dental caries; however, the knowledge base for the diagnosis of dental caries and risk assessment has not significantly progressed during the last five decades. There has been limited investment in clinical research and the translation of research and biological knowledge into practice. Moreover, dentists still rely on observations and uncontrolled experimentation with a few patients to make general recommendations for dental practice.(10)

The successes in prevention of dental caries and restorative treatment occurred due to the success of the application of the scientific method. As will be documented in the papers to be presented in this conference there are still significant gaps in the knowledge base for dental caries diagnosis and management. This historical review shows that many of the problems that will be discussed by the next presenters have been known for a long time; we need to find solutions. For caries diagnosis and management there is an urgent need to develop and test new protocols and tools that can accurately diagnose the earliest signs of tooth demineralization and provide clinically useful information on the determinants of progression and regression. There is also a need for consensus on the stage at which a decayed lesion should be surgically treated. Research on these issues will not be possible without some major funding initiatives to support the training of a new cadre of basic and applied researchers in cariology, and to develop and implement programs to address the real-life problems in diagnosis, risk assessment and management. If the current weak support at the NIDCR and its review committees continues, history will be harsh on all of us for our failure to use our knowledge and resources to reduce, if not eliminate, the burden of one of the most prevalence diseases.

Introduction

The charm of history and its enigmatic lesson consist in the fact that, from age to age, nothing changes and yet everything is completely different.

Aldous Huxley - *The Devils of Loudun*

This paper focuses on the history of dental caries with emphasis on relevant developments in the second millennium. It provides a brief historical overview of important events, concepts, and scientific developments that have shaped our current understanding of one of the most common diseases in humans. In writing this paper we have focused on issues that are relevant to the agenda of the Consensus Development Conference on Dental Caries Diagnosis and Management Throughout Life. This historical review was not planned to be exhaustive, rather it provides a selective glimpse of the key findings related to the diagnosis, etiology, and management of dental caries.

In this paper, we will refer to findings from the pre-restorative and the restorative eras. During the pre-restorative era, although simple and crude restorative care was available, dental caries was mainly managed through either extraction of decayed teeth or resignation (individuals with carious teeth just tolerated and lived with condition and its sequelae). We have estimated this period lasted until the 1850s, even though we understand that any firm time division is artificial. In the middle of the 19th century, the restorative era began during the second industrial revolution. It is also around that time that major advances in understanding the biology and pathology of diseases in humans started to emerge.

Additionally, in the text of the paper, we have used the term the “observational era” to refer to a period of our history when healers observed diseases and their progress without using the scientific method to study and test hypotheses. By contrast, we refer in the text to the “scientific era” where observations, theories, and hypotheses were tested using systematic methods. It is during this period, or the last 150 years of human history, that the knowledge base on causes and treatment of most diseases has rapidly advanced. The scientific era has had the most significant impact on the quality of life and on health of humans.

This paper is not a systematic review of the history of dental caries diagnosis and management. For this review of the history of dental caries we have searched for evidence by handsearching the Index of the Dental Literature published between 1839 and 1965 (studies published after 1965 have been reviewed by the other authors in this conference). We have selected articles that are relevant to the diagnosis, etiology, and management of dental caries. We also have reviewed about 40 textbooks on dental caries or the history of dentistry and selected recent key articles that we considered having historical importance to the topics to be discussed later on in this conference. All documents were read by one or more of the authors and entered in an Endnote[®] database. The events described in this paper are based on information abstracted from around 350 references. Additionally, we have selected a few relevant references published after 1965. In this paper we have refrained from pointing out important developments after 1965 that have been covered by the other reviews in this conference.

Pre-Restorative Era (up to 1850 A. D.)

While dentistry is a young profession that emerged in the mid 19th century as a separate discipline that focused on treatment of diseases of teeth and their supporting tissues, dental and oral health problems have inflicted humans throughout history. Writings of Egyptians, Mesopotamians, Israelites, Indians, Chinese, Greeks Romans, Aztec, Maya, Inca, and Arabs have documented accounts of dental and oral problems and their treatments (11-12).

Egyptians papyri (starting at 3,000 B.C.) have identified a person referred to as “the one who deal with teeth” and described how teeth can be “strengthened”. Archeologists have found mandibles with pore-holes that evidently were drilled to treat abscesses around teeth. They also found gold wire ligatures around loose teeth.

In the 18th century, B.C., King Hammurapi of Babylon described in details the practice of medicine (and dentistry) at the time. (12) In his civil code, the principle of “a tooth for a tooth” was described and a tooth was valued at 1/3 the value of an eye. Tooth color was also used to diagnose diseases of the “lip and tongue symptoms” as well as crowding, saliva flow, grinding, and tooth loss. The code also described remedies for tooth worms and loosened teeth. The code also described methods to keep the teeth clean.

In ancient Israel, the beauty of teeth was referenced in the Talmud as well as the claim that an edentulous man is unfit to serve as a priest. Decayed teeth were considered as a sign of weakness and sound teeth were considered as a sign of force and vigor. The beauty of the teeth was admired. The uncomfortable sensation brought about by the drinking of acidic drinks was mentioned in religious writing. Prophet Jeremiah associated “sour grapes” with teeth.(13).(Chapter 31 verse 29: *In those days they shall say no more, The fathers have eaten a sour grape, and the children's teeth are set on edge.*)

In India, the Bower manuscript (600 A.D.) (The Bower Manuscript is a fifth century Buddhist text on medicine and "necromancy".) included prescriptions for the care of teeth and mouth. During the first six centuries A.D. structured training of physicians was described for members of the Brahmin caste (priestly caste).(12) The first classification of oral and dental diseases appeared around 650 A.D. and dental instruments were developed to clean teeth (toothpick, tweezers, among others) and to assist in tooth extractions.(12)

The Chinese were the first to use a toothbrush and used “amalgam” to fill cavities in teeth (659 A.D.). In the Mongolian dynasty (about 1,280 A.D.) medicine emerged as a specialty. Dentistry was one of the medical specialties. Acupuncture was used to treat dental diseases.

The Aztec connected dental hygiene with body hygiene and developed extensive herbal treatments for different dental or oral diseases. The Maya drilled and filled teeth and placed jade stones in teeth. The Inca abraded teeth, placed gold inlays, and replanted teeth.

Greco-Roman medicine included detailed observations on etiology and treatment of dental caries. Hippocrates developed the concept of “scientific medicine”. Galen described dentistry in his pharmacological text and recommended the drilling of teeth. Treatments for dental caries, loose teeth, jaw fractures, and infections were developed during this period. Aristotile described the blood supply for teeth and alveoli. Hand instruments were developed to drill and extract teeth.

The Islamic period, while it helped to bridge the Eastern and Roman-Greco civilization, introduced a number of new developments. The siwāk was used to clean teeth; and to this day daily prayers are preceded by oral and general hygiene practices. A scientist living in the 9th century (Tabit ibn Qurra), contended that the cause of dental caries was acid moisture in the mouth and he recommended filing away the early sign of dental caries. El-Razi, the father of Islamic medicine, was hesitant to extract teeth and recommended saving them using “astringent agents” and cauterization. Ibn Sina (Avicenna), only occasionally approved extraction. Several dental instruments that may have been used to extract or file teeth have been dated to the period 632 to 1250 AD of the Islamic era.

The Islamic period helped to translate and transfer the knowledge base of the Greeks and Romans to Europe during the years of the second Millennium. Medical schools in Europe used the Latin translations of medical texts written by Avicenna and other Islamic scholars. The natural sciences started to develop in the middle of the 15th century. In this period of Renaissance, artists became interested in the anatomy of the face. Leonardo da Vinci and Andreas Vesalius made several sketches of the skull, mandible, teeth, and facial profiles.

The understanding of dental caries, its causes and treatment, did not advance much until the 18th century. The first full text on dental diseases and their treatment was published in 1728, where Pierre Fauchard, a French surgeon, wrote the “Le Chirurgien Dentiste”. This two-volume textbook, included sections on every area of dentistry: prevention, prosthetics, surgery, orthodontics, dental medicine, and dental instruments. He rejected the toothworm theory of dental caries. He described enamel hypoplasia as “an erosion of the enamel” (12) and recommended that hypoplastic areas be smoothed using files. Fauchard’s textbook had detailed sketches of instruments used to treat dental caries including files, sharply curved pointed instruments to remove caries; condensers, carvers and metal strips. He recommended total excavation of carious lesions and filling cavities with lead, tin or gold foil. Fauchard’s textbook set the stage for similar pioneering work in Germany, Austria, and England. Experiments on causes of dental caries, no longer related to worms, started from the middle of the 18th century. The first experiments were conducted on the behavior of teeth in acids (12). (A recent report from China suggested that the toothworm theory is still the basis for treatment of dental caries by “quacks”. (14))

Until the 18th century, dental treatment was rather simple and was based on extraction of teeth, use of traditional remedies or, as described before, resignation (giving up). Oral health promotion was based on myths and folklore. (For example, in the 11th century, the famous nun, Hildegard von Bingen, suggested that the “one who wishes to have hard, healthy teeth should take pure, cold water into his mouth in the morning, when he gets out of bed”. (15)) With the beginning of the Second Industrial Revolution in 1875 (telegraph, transatlantic cable, telephone, incandescent light bulb; diesel engine; wireless communication; and airplane flight), dentistry was on the verge of experiencing a new revolution that focused on conserving teeth rather than extracting them.

The Restorative Era: 1850– present

By the middle of the 19th century, Horace Wells (DDS) discovered general anesthesia; Roentgen discovered X-rays; and the rubber dam and the dental engine were developed. The so-called “American dentistry” became known as practice focused on restoring teeth using different filling materials. Technological advances, however, did not influence biological thinking and decision-making. An English physician, William Hunter, criticized the “American” method of restorative care in that it did not improve the oral hygiene of patients and did not remove all infected tissues (story reported by Coleman (16)). Dr. Hunter started to remove infected teeth; bridges and crowns; and teeth with extensive restorations and reportedly observed an improvement in the general health of his patients. Dr. Hunter in a speech at the Faculty of Medicine, McGill University, referred to the poorly constructed bridges as “mausoleums of gold over a mass of sepsis”. Dr. Hunter claimed that systemic disease could be traced to infections around the teeth.

The “focal infection” theory may have started with studies in the early part of the 20th century when Dr. E.C. Rosenow associated *S. Mutans* with infective endocarditis and the formation of gallstones.(17) The presence of foci of infection in the mouth was identified over 100 years ago. Physicians blamed the teeth for many ailments and recommended removal of teeth. Dentists were reluctant to perform wholesale extraction of teeth. In 1916, Ernest Hemingway wrote a column criticizing the fad of blaming “all the ills that flesh is heir... to on our teeth” (18).

With the start of the second industrial revolution, significant economic and social changes took place in Europe and the U.S. The dispersion of wealth and the creation of a class of middle-income working families in large cities created new demands on all services and professions. The movement for restoring rather than extracting teeth started to gain momentum almost 150 years ago.

Late in the 19th century, dentists were faced with an increasing demand to conserve teeth from the ravages of dental caries. Amalgam was first used in Europe, but in 1855, Drs. W.M. Hunter and Elisa. Townsend from the US, published a formula of amalgam that consisted of tin, silver, and mercury.(12) While amalgam was initially criticized because of its mercury content and poor physical properties, it was improved and became the material of choice by the end of the 19th century. Adhesive gold was developed and used in practice by Dr. R. Arthur (one of the first students of the Baltimore College of Dental Surgery).(12) The techniques for filling teeth with amalgam or gold were also improved. In 1883, a battery-powered electric dental engine was developed. The mechanical era continued to ease the practice of dentistry with the development of faster dental engines and handpieces during the late 19th century. These developments were not concomitantly associated with advancement in knowledge of the diagnosis, etiology, and management of dental caries. This task was left to the pioneering works of Tomes, Webb, Black, and Miller, among others (12, 17, 19).

Etiology of dental caries

The only completely consistent people are the dead. - Aldous Huxley

Dental caries is a complex disease. The “cause” of dental caries has received significant attention in research during the 19th and most of the 20th century. During the observational era

different causes were associated with dental caries. The dominant theory as we entered the scientific era that started in the middle of the 19th century, was the “worm theory”. (20) In 1868, Drs. Leber and Rottenstein published their work on “dental caries and its causes”. They advanced the theory that the disease was caused by “fungi”, referred to then as “leptothrix buccalis”. (20)

At the International Medical Congress, held in London in 1881, Drs. Miles and Underwood proposed, after four years of investigations with patients, that dental caries development is dependent on the presence and proliferation of “organisms”. They proposed the so-called “septic theory”. They claimed that dental caries is caused by direct action of microorganisms that penetrate the dental tubules and destroy the organic component of the dentin leaving the inorganic parts to be broken down and washed away in fluids of the mouth. (17,21-22)

In 1881, at Wiesbaden, in Germany, at a meeting of the American Dental Society of Europe, a young American dentist, Dr. W. D. Miller, presented the results of his experiments that were conducted in the laboratory of the famous bacteriologist Dr. Robert Koch¹. (22) Miller’s studies found that acid produced by microorganisms in the mouth caused caries of the enamel, and caries in dentin resulted from acidic decalcification. Bacteria produced the acids that led to the demineralization of enamel and dentin and he also noted that bacteria did not need to be present in enamel or dentin to initiate demineralization. He also succeeded in producing artificial caries that was not different from the natural carious lesions he had seen in studying thousands of teeth. (5)

In Miller’s quest for answers to the causes of dental caries he made two very important, and yet overlooked comments. First, he warned all those searching for bacteria that caused dental caries with the following statement:

I have hunted for them [bacteria] day and night, and have found enough of them, but I have come to the conclusion that a satisfactory explanation of the cause of caries can never be obtained through the microscope.(5)

And second, he concluded that

The fact that a mixture of starch containing food with saliva, at the temperature of the human mouth, generates in a space of four to six hours acids sufficiently strong to soften tooth tissue, is absolutely undisputable. (5)

Miller’s research led to a storm of debate and controversy. One sentence in Miller’s responses to his critics describes the problems of relying on observation rather than experimentation to test hypotheses. Miller succinctly said

¹ A German bacteriologist. He devised a method of staining bacteria with aniline dyes and developed bacteriological culturing techniques. He established the bacterial cause of many infectious diseases, including anthrax (1876), tuberculosis (1882), conjunctivitis (1883), and cholera (1884), and studied sleeping sickness, malaria, bubonic plague, and other diseases. For developing tuberculin as a test of tuberculosis he received the Nobel Prize in 1905. <http://www.encyclopedia.com/articles/07036.html>

The principal feature in all of the publications which have as yet been made on this subject seems to me to be a lack of method, and perhaps in some cases an improper conception of the question to be solved. (5)

In our opinion, the two principal factors that led to the adoption of Miller's theory especially by American dentists and their organizations were the replication of his work by G. V. Black, "a man whom we all [dentists] honor" (22), and the credibility of Dr. Koch who supported the experiments and confirmed the findings of Dr. Miller.

Following the dissemination of Miller's findings, dietary and nutritional factors received extensive study for most of the last 150 years. Again, much of what was reported was based on observations such as those related to the physical and chemical characteristics of diet or those related to nutrients. Some authors had associated dental caries with changes in diet associated with "civilization"; (23-25); others related dental caries to changes in the environment surrounding teeth such as saliva, diet, and microorganisms, (26-33) while others thought it is related to changes in the structure of teeth. (34, 35) By the mid 1920s, it seems that the environmentalists won over those who advocated that the structure of teeth play a major role in the caries process. (36) (The nutrition-caries hypothesis was partially discredited by the findings that populations who were malnourished had lower caries prevalence than those who were well nourished (37) and by the findings from the pivotal, and undoubtedly the most unethical study ever reported in the dental literature, the Vipeholm Dental Caries Study, which found that frequent consumption of sugar increases the risk of developing dental caries.(38))

Early in the 20th century, after the passing of Miller and Black, questions were raised about whether the full causes of dental caries were understood. (36) Some asked the question, "why are some teeth immune from, [and] others susceptible, to caries...?" (39). This variation was attributed to difference in the calcification of teeth. (39) This hypothesis was also used to explain the individual variation in the resistance of enamel surfaces to caries. (40) Different explanations were sought for the observation that not all teeth are equally susceptible to dental caries and not all individuals, even when they have the same living conditions, experience dental caries.(41, 42)

Around 1910, Dr. W.J. Gies, a professor of biological chemistry at Columbia University, was invited by The New York Institute of Stomatology to carry out "an aggressive and alert investigation of the subject of dental caries." (43) He teamed up with Dr. A.P. Lothrop, to investigate the role of saliva and oral microorganisms in causing dental caries.(29, 43-47) Their work failed to show any definite "relation between the general composition and qualities of a given fraction of saliva and the conduction of the teeth".(43) and they concluded that "direct external attack upon teeth by microorganisms appears to be the most important single factor in the carious processes." (43) Gies described the role of the "viscid mucinous coating" on the teeth in the caries process and the role of saliva in neutralizing acids formed by bacteria.(46)

Dr. R. Bunting (the first laboratory technician of Dr. Miller at the University of Michigan) continued this line of research. He declared in 1914 that the "two greatest controlling factors in the process of caries are the food supply and the plaques." (48) Subsequent research confirmed this conclusion. (49) Studies conducted during the 1940s showed that while there were no differences between caries active and caries-free in calcium and phosphorous concentrations in saliva (50), there were differences in acidic profiles of plaque between the two groups. (51, 52)

Some saliva constituents may play a role in neutralizing the organic acids produced in plaque. (53)

By 1956, topical fluoride applications and local measures to control plaque through mechanical means were widely adopted by dentists (54) and most dentists started to move away from testing of lactobacilli in saliva and diet control. (54, 55) In 1956, it was reported that 43% of dentists either occasionally (37%) or routinely (6%) conducted tests of salivary levels of lactobacilli. (56).

On the topic of trace elements and dental caries, a short article published in 1894 referred to the presence of iron in teeth of a “hundred and fifty iron workers”. (57) Workers exposed to iron had stained teeth and heavy calculus accumulation. (57) In 1914, the first mention, perhaps, appeared of an association between lead exposure and dental caries. (58) Just prior to World War II, there were reports associating “poverty” and race with dental caries. (17, 59)

Throughout the 20th century, many researchers and dentists recognized that dental caries is a product of interplay of many factors. (46, 60) In his article “dental caries redefined”, Dr. P. Keyes, explained the interplay between the local cariogenic bacteria in plaque, fermentable carbohydrates, “constitutional factors” related to “species and strains”, and the tooth structure. (60) The work of Drs. Keyes and Fitzgerald proved that dental caries is an “infectious process” of the teeth. (61, 62). The impact of these findings on caries management has not yet been realized; even though studies have shown that the level of cariogenic infection can be reduced using anti-microbial agents. Currently, dental caries is considered a multifactorial disease with “an interplay of three principal factors: the host, the microflora, and diet. Time provides an important fourth factor for considering the etiological burden in causing decay of enamel and dentin.” (64) This model is still valid today, even though, we may know more about the biological determinants and interactions among the different factors. (9)

Definition and diagnosis of dental caries

Facts do not cease to exist because they are ignored.

Aldous Huxley

An anonymous German manuscript published in 1530 defined caries as “...a disease and defect of the teeth in which they become full of holes and hollow, which most often affects the molars, especially if one eats and does not clean them of the adhering food, which decomposes, producing a bad acid moisture which eats them and corrodes them out, increasing continually little by little so that it destroys the teeth entirely, which thereupon finally rot away in pieces, not without pain.” (reported by Kirk in 1913. (64))

By 1880, dental caries was defined as a “disintegration of the tooth substance, molecule by molecule”. (65); and a disease that is caused by the fermentation of “foods” inside the mouth. (17) Dental caries was recognized as a process that always started on the surface of teeth and progressed slowly towards dentin. (65) and progresses more rapidly in dentin than in enamel (65). It was also observed that decay is not found on tooth surfaces that are “smooth and constantly worn by attrition or mastication”. (65)

Prior to the work of Dr. W. D. Miller and his chemico-parasitic theory (66) there were reports of “hidden caries” or “caries interna”. The detection of a carious lesion deep into dentin in teeth that had either no evidence of caries when examined clinically or only had a small “pin-hole

cavity” (67) led to the theory that caries was initiated inside the tooth structure. The problem of “hidden caries” seems to have been noticed as early as 1868. (2)

By the 1880s, dental caries was recognized as a process that may show as “decalcification” or caries in the enamel. (68,69) Magitot advocated filling enamel carious lesions if they are detected on occlusal tooth surfaces and abrading them on smooth tooth surfaces. Others advocated restoring these early carious lesions because follow-up of such lesions showed that rapidly progressed into dentin. (70)

On the subject of enamel caries, Dr. G.V. Black presented in 1910 a plea presented before the Academy of Stomatology, College of Physicians and Surgeons, Philadelphia, which succinctly summarized the importance of diagnosing dental caries as a process.(20) Black in a prophetic evaluation of dentistry in the early part of the 20th century, pleaded with dentists to investigate the chemico-bacteriological phenomenon in the mouth and caries in enamel.(20) Black had observed that caries in enamel, or early caries, “appears in the teeth of patients ...from day to day” and these lesions were usually found in pits and fissures of occlusal surfaces, proximal and labial and buccal tooth surfaces. He contended that “the whole subject of caries of the enamel is the most important one in its relation to everyday practice, and I think it is not best to give to our students in the junior or freshman year, but we want it in the senior year, and we want the study of it in the whole profession.” (20)

Dr. G. V. Black observed in 1909 that “the craze for crown work, bridge work... was spreading over the dental horizon, and little else could claim or hold the attention of the average practitioner.” (20) This trend in dental education and practice has continued for much of the 20th century. Even after experimental studies on enamel caries in 1947 and 1949 described the histopathology of enamel caries (71, 72) and the microporous structure of enamel lesions (73) textbooks on restorative dentistry did not, until the 1990s, pay any attention to the area of diagnosis of dental caries and detection and prevention of early carious lesions. Some operative textbooks emphasized only the detection-treatment decisions rather than diagnosing the carious process. (74, 75). Even in the year 2000, some dental “experts” have failed to recognize the phenomenon of early carious lesions and advocated the immediate restoration of such lesions. (10) And, neither the reimbursement system for dentists nor the evaluation systems of dental students have recognized that the detection and remineralization of enamel lesions as activities for which dentists or dental students should be recognized for doing.

The reference to “dental caries” as “cavities” seems to have started in the early part of the 20th century. (76) Sogannes, in 1940, defined “pre-caries” as a “lesion that could not be detected by the explorer as no roughness was noticed on the surface.” (76) He recommended recording “enamel caries” because it is “important from a practical viewpoint...[to] offer the possibility of prophylactic treatment”. (76)

At a 1948 consensus conference, dental caries was defined as

... a disease of the calcified tissues of the teeth. It is caused by acids resulting from the action of microorganisms on carbohydrates, is characterized by a decalcification of the inorganic portion and is accompanied or followed by a disintegration of the organic substance of the tooth. The lesions of the disease predominantly occur in particular regions

of the tooth, and their type is determined by the morphologic nature of the tissue in which they appear.” (77)

The use of radiographs to diagnose “hidden caries” was proposed in 1912. Drs. Bodecker and Bodecker of Berlin, Germany, published a description of how radiographs can replace the conventional system of tooth separation to detect carious lesions. (78)

Arrested caries was described in 1880,(65,79) and in the early part of the 20th century.(80) The presence of arrested caries was considered “of value” in determining the susceptibility of an individual to caries. (81) The histopathology of these lesions was described in 1956. (82) Recommendations to arrest or cure dental caries via cleaning to remove bacteria had been suggested in 1909. (83)

Secondary caries is a condition that was identified as a problem in 1880. (3) Dr. G.V. Black reported on “leaky filling” and that fillings offer “little protection. He also concluded that his patients who have been treated with gold are less likely to have recurrent caries. (65)

The condition we call now “early childhood caries” was described at least by 1884 as the “labial decay of childhood”. (1) The condition started on the enamel of the labial and buccal tooth surfaces and a green or brown stain usually precedes it. For these lesions, “prophylactic” as well as mechanical and “constitutional” treatments were recommended. Interestingly, a dentist observed that the “labial decay of childhood” often “arrests itself before [it] had penetrated the whole thickness of enamel.” (1) In 1912, the term “comforter caries” was coined by Harries based upon observations made of children who had otitis media and used “comforters” or “pacifiers”. (84)

Dental caries has been classified based on the type of tooth surfaces affected for almost 100 years. (85) Pit-and-fissure caries was commonly observed in young individuals. In 1922, Friesell recommended that restorative treatment for these lesions should be conservative and there is no need for “extension for prevention”. (85) Friesell also identified carious lesions on the “proximal”, “gingival third” and “senile decay, which begins ... beyond the gingival line”. (85)

The variation among dentists in diagnosing dental caries is not a new phenomenon. A dentist reported, in 1869,

that there are some cases of failure in diagnosis of dental decay, even when one intends to be very thorough. First and foremost is the large size of the excavator used for examination. The diagnosis excavator should be of the very smallest kind, and hatchet shaped..... This excavator should be made for diagnosis alone, and not for cutting enamel or dentine.” (4)

The variability of diagnosis among dentists was also noted in 1941 in a study that included 8 dentists “all of whom had years of clinical experience and who were considered careful investigators” and 33 individuals who were examined consecutively by at least 3 of the dentists. (86) The examiners only agreed on the number of carious teeth for one individual out of the 33 examined. (86)

Preventive management

As described earlier, there have been many folkloric remedies used to prevent dental caries. The answer to the question “what can we do to prevent dental caries?” by the end of the 19th century was best described by Huxley’s statement that:

...we are still very far from being able to give it a satisfactory answer, our knowledge of the etiology of caries being too limited and uncertain. We find ourselves obliged to evade the question, and go on patiently plugging cavities as they appear; perhaps, in addition, prescribing some local remedy when the conditions are obviously unhealthy. (79)

In that environment, many interventions were suggested based upon observations that had not been rigorously evaluated. For example, some suggested that because crowded teeth are more susceptible to caries, it was recommended to extract the first permanent molars as soon the second permanent molars erupt.(87) Others suggested “cutting away the tooth structure” to relieve the crowding and prevent dental caries; (88) the use of “antiseptics”; (89) tooth cleaning solution; (90) brushing and flossing the teeth; (91) and eating of foods “to promote the formation of strong teeth”.(91, 92) It is also interesting to note that some dentists have suggested that “...for white or light brown decay, found in the mouth of children or patients in their teens, and of pregnant women..., carbonate of lime, ...or phosphate of lime, ... is wonderfully efficacious”. (90)

One of the most scientifically untested slogans in dentistry has been and still is, to some extent, the concept of “extension for prevention”. Dr. M. H. Webb proposed this concept over 100 years ago. (93) It was slightly modified by Dr. G. V. Black as a means to prevent the recurrence of decay as well as to ease the placement of a restorative material and ease oral hygiene care for restorations placed to replace mesial or distal decayed tooth surfaces.(94). Despite the lack of scientific documentation supporting the concept of extension of prevention,(95) its liberal use in cavity preparation continued for most of the 20th century. Extension for prevention was not indicated for occlusal surfaces. For occlusal surfaces, several solutions have been suggested to prevent the fissures from developing dental caries. These included prophylactic odontotomy, fissure eradication, application of impregnating solutions (for example, calcium salts, silver nitrate, zinc chloride), (96) and the application of non-adhesive dental materials (zinc phosphate and copper cements). (63)

At the beginning of the scientific era, biological findings or observations were used to develop clinical solutions before researching the benefits, risks, and usability of the proposed interventions. For example, in 1883, when the association between dental caries and microbial factors was reported, recommendations were made to clean the teeth; by applying “sulphurous acid”, carbonic acid, iodine, bromine, chlorine, and zinc chloride (89) or silver nitrate.(84) This inductive process from observations to clinical applications without scientific validation has been a common practice, with a few exceptions in dentistry. The myth of “clean teeth never decay” was challenged in 1912 when Dr. D.W. Barker of Brooklyn, New York, questioned whether teeth could be kept “surgically” clean for long enough time to prevent them from decay. (97) Nevertheless, the practice of “cleaning” teeth in dental practices was universally accepted in the early part of the 20th century, and by 1912 there were calls to train “dental nurses” to meet the professionally perceived need for “examination and cleaning of the exposed surfaces of the

teeth.”(98) It is also interesting to note that in 1913, there were those who believed that the ideal solution to caries is “physiologic prophylaxis”, a protocol that relies exclusively on self-care at home and eating foods that promotes “alkalinal saliva”. (99), drinking of fruit juices, (46), eating “fibrous foods” and restricting the eating of “sticky carbohydrates”. (100)

In 1907, Dr. W. D. Miller suddenly died, possibly from appendicitis and was eulogized as a “scientist.” (101) He started the field of “biological sciences” in dentistry and his influence on his contemporaries, especially G. V. Black, was significant. (20) Around the time of Miller’s death, a young dentist unknowingly ignited a new revolution, through his keen observations, in preventive dentistry. Dr. F. S. McKay, who was practicing in Colorado Springs, Colorado, noticed that many of his patients had “mottled enamel”. He pinpointed the problem, after several field investigations, to the drinking water. In 1930, H.V. Churchill, (102) a chemist with the Aluminum Company of America discovered that fluoride may be the cause for the enamel mottling, the condition that we now refer to as “fluorosis”.

In 1931, Dr. H. T. Dean was assigned by the United States Public Health Service to study the association between fluoride and “mottled enamel” which led to associating fluoride with reduced dental caries prevalence and severity. (103) Dean led a series of field investigations that confirmed the association between fluoride in the drinking water and fluorosis and the potential beneficial effect of fluoride in caries prevention. (8, 104) In a classical research program, a team led by Dean and others initiated a series of community-based trials to test the hypothesis that adding low concentrations of fluoride to the drinking water can be effective in preventing dental caries. (7) These studies showed that adjusting the fluoride concentration to around 1.0 ppm (parts per million) could lead to a significant reduction in dental caries prevalence and severity in children with minimal cosmetic side effects.

The emerging information on fluoride and its effect on dental caries and the finding that “...failure to meet the minimum standard of having six opposing teeth was a leading cause of rejection from military service in both world wars” (105), provided major impetus for establishing the National Institute for Dental Research (NIDR) in 1948. NIDR staff in collaboration with other dental researchers working for the US government conducted and supported research on the physiology, biochemistry, toxicity, and epidemiology of fluorosis and dental caries. The success of these research projects in reducing the burden of dental caries in US,(106) unfortunately, led, among other factors, to the premature cancellation of the National Caries Program in the early 1980s. Since then, the knowledge base in the US on caries diagnosis and prevention has not progressed significantly.

From the early 1960s through the late 1970s, the “Halcyon Days” (107) of fluoride research took place in the US and other parts of the world. (54, 108-119) While the mechanism of action of fluoride as a cariostatic agent is still being debated there is strong evidence that fluoride given either systematically in drinking water or applied topically through exposure to fluoridated water, toothbrushing, or other means is effective in reducing the burden of dental caries. (6, 108-131) By the 1950s, topical applications of fluoride were widely provided by dentists in the US.(54)

Although fluoride is effective in preventing caries on all tooth surfaces, occlusal surfaces remained the most vulnerable to caries attack. A major breakthrough in resolving this problem came when it was discovered that creating small tags or roughness on the enamel surface by the

application of a weak acid (phosphoric acid) significantly enhanced the retention of an acrylic filling material. (132) This discovery led to a series of research initiatives on acid etching, adhesion, and materials for preventing dental caries in pits and fissures. A new material, bis-(4 hydroxyphenol)-dimethylmethane and glycidyl methacrylate (BIS-GMA) was developed in the early 1960s and had better properties than previous materials that were used to seal the pits and fissures. (133) The BIS-GMA resin (without filler) was shown to be effective in preventing dental caries initiation or progression when applied to seal the pits and fissures of teeth. Sealants have unfortunately received limited acceptance by the dental profession. (134)

During the 20th century, other approaches have been proposed and tested to prevent dental caries. In the early 1940s, it was evident that patients who are caries-active frequently consume sugar-containing drinks or foods. (135); however, attempts to reduce the frequency or amount of consumption of sugary foods and drinks were not successful when applied by dentists or in community settings. (136-137) In 1945, a paper was published on the reduced fermentation of sorbitol in saliva and the potential use of this natural sugar as a substitute for sucrose (sugar), (138) and an experiment conducted in 1956 confirmed this finding. (139) Research for finding alternative sweeteners led to the testing of xylitol in clinical trials in Turku, Finland, (140) and of adding xylitol to chewing gum. (141)

Restorative Decision Making

For most of the 19th and 20th centuries, dental caries was managed through removal of demineralized enamel or dentin and placing synthetic materials to restore anatomical form, function and esthetics. While the restorative philosophy is still dominant among dentists, the techniques of preparing teeth and the materials used to restore teeth to its original form underwent significant evolution during the 20th century.

In addition to the technological advances in anesthesia and tissue cutting instruments and devices (handpieces), the field of restorative dentistry has benefited significantly from the revolutionary advances in developing new dental materials and the invention of the dental air turbine handpiece in 1946. (12) These advances have led to the provision of sophisticated restorative care and, consequently, the saving of teeth. However, failure to deal with the problem of diagnosis and decision-making may have led to over-restoration as well as under-restoration of decayed teeth. (142-143) Nevertheless, there has been a significant decline in the need for restorative care during the last decades of the 20th century. (144)

The “drill and fill” approach represents one model for treating dental caries. This model, which is still advocated in the year 2000, (10) calls for the surgical opening of a tooth whenever dental caries is detected, removal of the decayed tissue, and placing synthetic materials to restore the form and function of decayed teeth. While this model has been successful in treating the disease, it has failed in managing the disease process. (145) Secondary caries (around the margins of restorations) remains in the 20th century as the major ostensible reason for re-restoring teeth. (146-147) Restoring decayed teeth does not eliminate or reduce the burden of cariogenic infection. (148) The significant variation in restorative decision-making noticed among dentists in the 19th century, (4) still remained in the 20th century. (142,143)

This approach of managing dental caries has its roots in the “mechanical” development of the art of dental care. Early in the 20th century, G.V. Black warned against the overly zealous mechanical approach to treat dental caries. (20) He was not alone with such a concern. Gies in

his classical report on dental education raised concerns about the focus on technical thinking and approach to managing dental caries, with neither considering the scientific nor the biological basis for management. (149) In 1939, there was a call to develop the concept of remineralization as “one of the next big topics in dentistry”.(150) This call has yet to be answered. In fact, by the end of the second millennium, neither dental students nor dentists were rewarded for saving teeth with early carious lesions from being surgically drilled and filled. They are not rewarded for remineralizing early carious lesions.

The attempt to deal conservatively with dental caries seems to have picked up momentum in the last 10 years of the 20th century with the advent of new materials and tools. The third edition of a major textbook of operative dentistry has included a detailed chapter on caries diagnosis.(151) The most common practice today is still the complete removal of all soft decayed tissue regardless of the level of infection and histological destruction. A number of studies that have tested the outcomes of sealing-in dental caries, even when it is in dentin, have documented successful outcomes.(152,153)

There have been calls for changing the paradigm from “drilling and filling” to managing the disease as an infection.(154,155) However, there have not been any studies that evaluated the outcomes of such an approach and, moreover; some dental schools do not teach or practice this model;(156) the dental care systems in the US and other countries do not reimburse or promote such an approach. Instead, the routine provision of “prophylaxis” and professional fluoride application has been the main form of preventive care provided by dentists.(157)

The 1948 Consensus Conference on dental caries diagnosis and prevention

That men do not learn very much from the lessons of history is the most important of all the lessons of history. -- Aldous Huxley

We were surprised to find that over 50 years ago a consensus conference was organized to “sift out facts from myths in one of the major areas of concern of the dental profession [dental caries]”. (77) What is noticeable about that conference is that it was perhaps the first conference where experts were required to justify their recommendation with scientific evidence. The scientific basis for diagnosis and prevention of dental caries were eloquently described by Dr. K. A. Easlick (77), the organizer of the conference. By presenting his guidelines for decision making to the experts attending that conference, he stressed the need to evaluate the source of evidence; the authors; setting where data were collected; research question; evaluation of outcomes; control of modifying factors; detailed description of study participants; and statistical methods. He cautioned against using coincidental findings to claim “cause-and-effect” relationships. That conference is perhaps the first one in dentistry that attempted to scrutinize the scientific evidence with the help of statisticians.

The checklist used at that conference to reach consensus included the following (77):

- I. Qualifications of the investigator
 - A. Training
 - B. Experience
 - C. Available experimental subjects
 - D. Available equipment, funds and personnel
- II. Selection of preventive or therapeutic measures

- A. Safety
- B. Simplicity
- C. Acceptability to the public
- D. Availability to the public
- E. Cost
- F. Likelihood of abuse
- G. Composition and degree of purity of test materials
- H. Blind test methods should be employed where practical
- I. Methods and preparations used should lend themselves to immediate practical application through established facilities
- J. Mechanism of action of drugs should be understood before general use is recommended
- III. Selection of test subjects
 - A. Number
 - B. Distribution by age, sex, strain, environment, diet, habits, health status
 - C. Establishment of experimental and control groups
 - D. Adequate discipline
 - E. Stable population
- IV. Preliminary survey and observation of test subjects
 - A. Diagnosis
 - B. Observation of test subjects for an adequate period before preventive or therapeutic measures are started
- V. Duration of study
- VI. Statistical evaluation of results

On the importance of critical appraisal to oral health, Easlick defined the following guidelines:

- I. Methods known to be effective should be used until better methods are established by research.
- II. Caries-prevention does not of itself lead to oral health (e.g. regular prophylaxis)
- III. Reliance upon ineffective or hazardous methods is inadvisable.
- IV. Any method for control of caries must be accepted by the profession and the public before it will be practically effective.

These principles were used to evaluate the state of science at that time. The conference agenda included the following (77):

- I. Measures which have been proposed for control of caries
 - A. Systematic
 - 1. Vaccines
 - 2. Hormones
 - 3. Nutritional agents
 - B. Mechanical
 - 1. Operative dentistry and orthodontia
 - 2. Toothbrushes, toothpicks, dental floss, and abrasive dentifrices
 - 3. Therapeutically inert mouthwashes
 - 4. Abrasive or detergent foods or confections
 - C. Chemical
 - 1. Detergents
 - 2. Impregnating and surface-changing agents
 - 3. Enzyme inhibitors

4. Alkalies
- D. Bacteriological
 1. Antiseptics
 2. Antibiotics
 3. Ammonia derivatives and quinine
 4. Implantation of bacteria

The leading dental and non-dental experts in these fields at that time, reached the following conclusions after critically reviewing the evidence (only a few example are presented here) (77):

On dental prophylaxis, the group agreed that “the scientific literature contains little scientific data on prophylaxis as related to dental caries, and, therefore definite conclusions are not possible”.

The literature indicates that thorough prophylaxis will remove bacterial plaques from the accessible surfaces of the teeth but not from inaccessible surfaces such as pits, fissures and contact points. The evidence presented is in the form of clinical observations and is not expressed in data which may be subjected to statistical analysis.

On frequency of professional prophylaxis, the consensus group concluded that “evidence has been presented that plaque will grow back over tooth surfaces in one to four days, which indicates that it is impractical to perform a prophylaxis frequently enough to prevent plaque formation.

These conclusions take us back to the quotation on the first page of this paper: “nothing changes and yet everything is completely different”. The lesson that we would like to leave the readers of this proceedings with is that knowledge by itself, especially when generated and communicated only among experts, does not usually lead to change of practices, unless a system is developed to promote change among educators, practitioners, and the public. Without understanding this simple fact, this new Consensus Development Conference will be another discussion exercise.

Today and the Future

The principal feature in all of the publications which have as yet been made on this subject seems to me to be a lack of method, and perhaps in some cases an improper conception of the question to be solved.(5)

The office of the dentist is not the proper place to observe and form opinions as to the prevalence of caries; neither are the poorhouses, hospitals, infirmaries, proper places to secure reliable statistical information as to caries and other diseases or conditions.... For neither the dentist's office, nor the public institution established for specific purposes contains or is visited by a number or class of people who are representative. (158)

So what have we learned from this brief review of historical developments in caries diagnosis and management? Looking at our progress throughout the second millennium, we have achieved unprecedented successes using the scientific method to improve not only the understanding of the caries process but also its prevention and treatment. The technical capabilities of the dental care system have dramatically improved during the last 50 years. Scientific research has been the most important tool that has advanced our knowledge and reduced the burden of dental caries in the US and other countries. In the 21st century, we need to re-establish new research programs on dental caries. These programs should be focused on resolving the problems that have been

described in the Surgeon General's first Report on Oral Health. (106) New advances in biology and engineering should open new doors for the prevention and management of dental caries, and most importantly, a better understanding of the etiology of the disease. These new research programs should develop new methods that can validly and reliably assess the caries activity in enamel and dentin. Advances in MicroElectroMechanical Systems (MEMS), nanotechnology, sub-micron fiber-optic biochemical sensors, energy transducer supermolecules (artificial photosynthetic antennae), and in-vivo nanosensors, open the door for new research initiatives to develop novel approaches to diagnose and prevent dental caries. Advances in tissue regeneration may open the door for new methods to restore tooth structure.

Research provides solutions to the future; today, however, we need to deal with current realities. Although we have reached a relatively high degree of excellence in restoring teeth, placing high quality restorations in teeth that should not have been surgically cut and restored represents the lowest overall standard of care. We must focus on resolving the current diagnostic dilemmas and develop protocols to reduce the chances of false positive or negative decisions. Our disregard for the complex issues of detection, diagnosis and decision-making in teaching and practice must be corrected.

The plea of G. V. Black, made in 1909, to study and understand early carious lesions (in enamel) should receive our utmost attention. (20) We need to focus on moving away from defining dental caries as "cavities" to detecting the stages of the caries process, as Magitot recommended in 1886. (68) In order to achieve this goal, we need to reward dentists for keeping teeth healthy and arresting or reversing early carious lesions. We also need to address this void in the current dental education system.

In prevention, dentistry has not developed any new innovations to prevent dental caries during the last 50 years. Fluoride is not the only solution and neither are sealants. And for these two interventions, and others like xylitol or anti-microbial agents, there is a need to develop protocols to define appropriate uses in clinical practices.

Finally, as Gies (45,46,149) and Black (20) warned us at the beginning of the 20th century, the dental profession must not develop its technological base at the expense of its biological foundation. We are on the verge of new revolutions in biology and engineering, on the verge of the integration of different scientific disciplines in the presence of dynamic information technologies. We cannot afford to remain isolated from the rapid changes occurring around us. We need consensus on how to best diagnose and manage the disease now and what we need to plan for in the near future. We need to develop a new scientific foundation in the biotechnology-information revolution that is about to unfold in the 21st century. Dental caries is still a major oral health problem in the US. (106)

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